MAV

Mars Ascent Vehicle

A Hybrid Mars Ascent Vehicle Design and FY 2016 Technology Development

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MSFC

Marshall Space Flight Center

JPL

Jet Propulsion Laboratory

California Institute of Technology

AFESB

Vehicle Systems • Aerosciences • Flight Dynamics

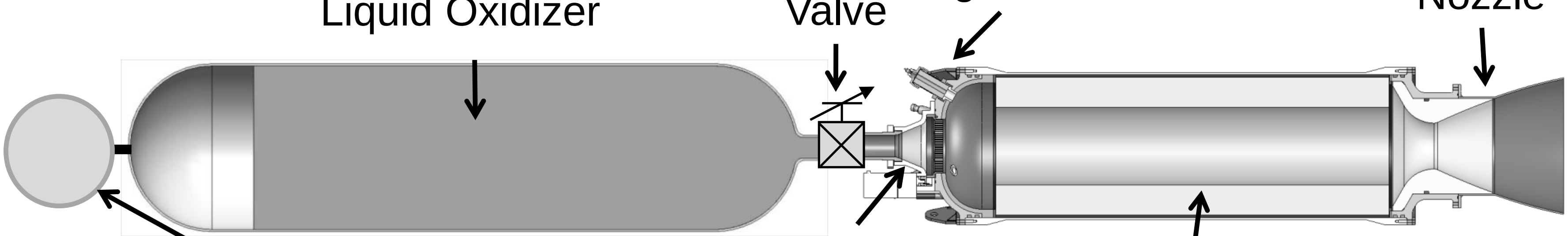
LaRC

Agenda

- Introduction
- Design
- Technology Development
- Challenges
- Future Work
- Summary

What is a hybrid rocket?

- Hybrid rockets typically utilize solid fuel and liquid oxidizer.
  - MAV is interested in this option because of its high performance, minimum need for thermal control and capability for multiple starts.

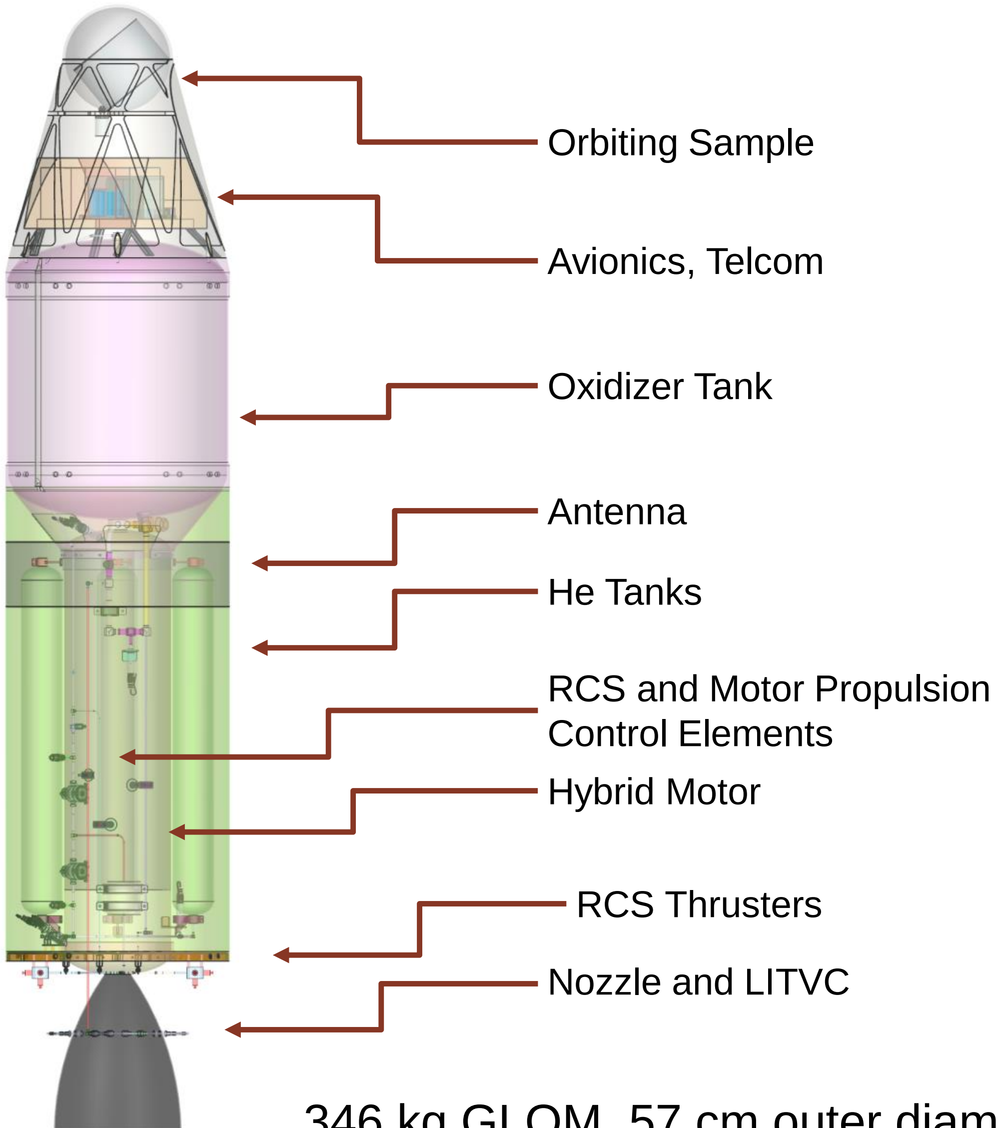


Fuel regression rate → $\dot{r} = aG_{ox}^{n}$ ← Empirically derived constants based on propellant combination

Oxidizer Mass Flux
(mass flow rate of oxidizer divided by the port cross sectional area)

Overview

Mars Ascent Vehicle



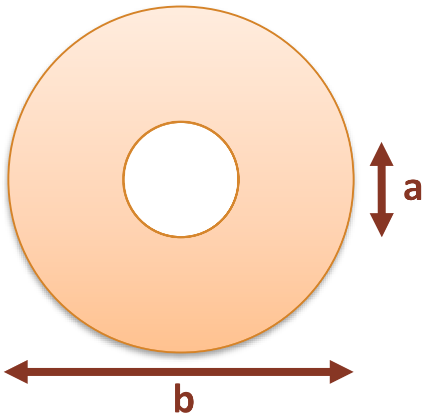
- The MAV uses a hybrid propulsion system with ***MON30 (70% N_2O_4+ 30% NO)*** oxidizer and ***SP7, wax-based***, fuel.
- The propellant combination allows for storage temps as low as ***-72 C***, reducing power requirements for an SRL host lander on the surface of Mars.

346 kg GLOM, 57 cm outer diameter, 2.9 m long

Design Details

Mars Ascent Vehicle

- There has been a steady mass increase due to increase in payload size, margin policy and change in target orbit.
  - Allocation for OS and upper rocket structure is 18 kg.
- Low pressure design – since the hybrid performance is only weakly dependent on chamber pressure, a low pressure can be selected: 250 psi. This minimizes the He loading required for pressurization.
- Efficient Fuel Loading: 88% of fuel core is fuel, b/a = 3.
  - Tested in a 7 cm motor
- Length to diameter (L/D) ratio is also near 3
  - Post combustion area is added to increase mixing
- Launch temperature of -20 C.



Areas of Technology Development

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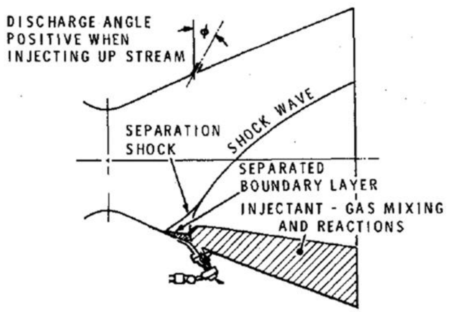
New Hybrid Propellant Combination

Hypergolic Ignition

Thrust Vector Control



LITVC system and thrust deflection effects

While the hybrid option showed the most promise, it is also the lowest TRL.

New Propellant Combination

- Hybrid MAV Propellant Desires:
  - Low temperature capability for fuel and oxidizer to minimize thermal control
  - Operation at low temperature (-20 C)
  - High performance
- Selected propellant combination: SP7/MON
  - SP7 developed by Space Propulsion Group.
    - Favorable low temperature behavior
    - High melting temperature, near 100 C
    - Lower regression rate (60-70%) than paraffin
    - Regression rate exponent near 0.5
  - Mixed Oxides of Nitrogen (N_2O_4 with NO)
    - MON3 is a good, room temperature surrogate for MON30 proposed for flight.

Wax-based fuel

Mixed Oxides of Nitrogen

MON3 = 0.97 N_2O_4 + 0.03 NO

Hotfire Testing: SPG

- Completed hotfire testing at the 7 cm scale with N_2O in 2015 and MON3 in 2016.
  - MON Testing to date covers a little more than half of the actual oxidizer mass flux range expected for the flight vehicle.
  - Full scale (11”) testing to begin in spring 2017

SPG
Advancing Propulsion & Energy

Fuel regression rate

$$\dot{r} = aG_{ox}^{n}$$

Empirically derived constants based on propellant combination

Oxidizer Mass Flux
(mass flow rate of oxidizer divided by the port cross sectional area)

Hotfire Testing: Parabilis

- Full scale (~10”) motor testing attempted at Parabilis.
  - Several short burns were achieved; however combustion stability and retention issues persisted and time ran out before a stable burn was achieved.

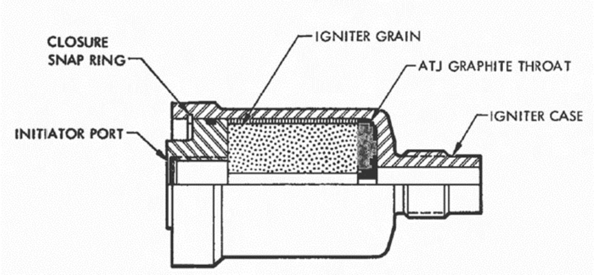
PARABILIS SPACE TECHNOLOGIES

Thermal Cycling of Fuel Core Samples

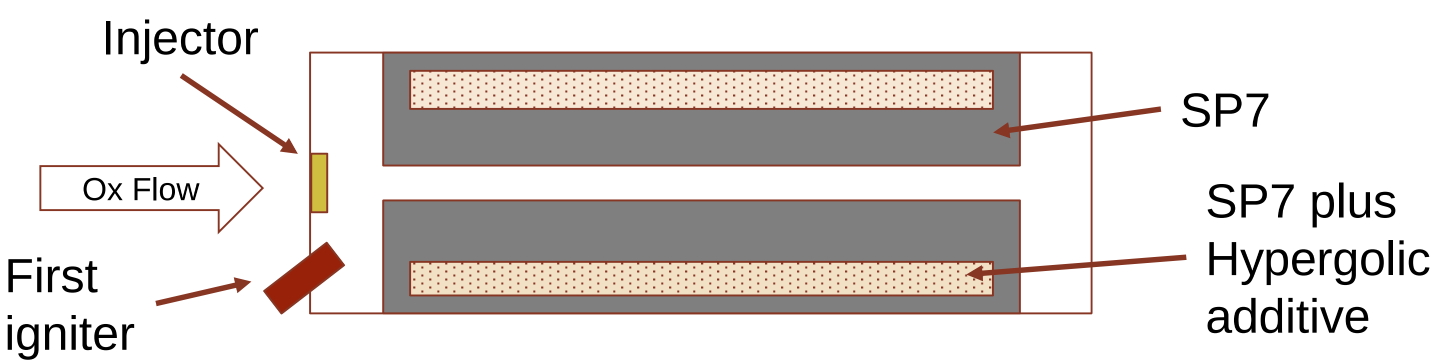
- Preliminary thermal testing completed at JPL to establish thermal rate limit using 2 samples.
- Completed 201 cycles at MSFC: 1 EDL cycle, 50 winter cycles, 100 spring cycles, and 50 summer cycles
  - 100 day test plan
  - 8 samples: four neat SP7, four aluminized SP7
- Gradient limits in ERD came out of thermal test failures
- Issues:
  - 2.5 inch thick samples, have not completed full length tests
  - b/a of tested samples was 2 instead of 3.
  - Some debonding was observed between the case and the fuel, but no radial cracking under Mars- like conditions.

Ignitors

- First burn ignition utilizes a standard pyro ignitor with redundant NSI's and fired by the lander PIU.



- Second burn: hypergolic additive in the SP7
  - *Hypergolic, Def: (of a rocket propellant) igniting spontaneously on mixing with another substance.*
  - A SP7 protective layer over the additive layer is envisioned for ground handling/stability. Wax has been shown to be a good inhibitor for these reactions.



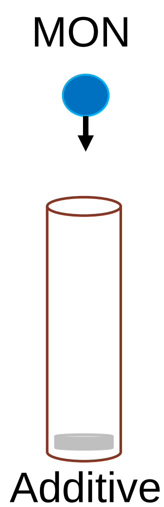
Search for Hypergolic Additives

- Penn State and Purdue conducted tests to determine additives to the fuel that are hypergolic with MON

- Drivers in the hypergolic testing:
  - It was assumed that additive's reactivity with NTO/MON3 would correlate directly with reactivity with MON30.
    - This is currently being investigated at Purdue with MON25 testing as a follow-on.
  - The additive must be solid
  - It must be hypergolic, not just reactive, with MON3
  - Target of less than 100 ms, ideally closer to 10 ms.

MON Drop Testing and Pellet Testing

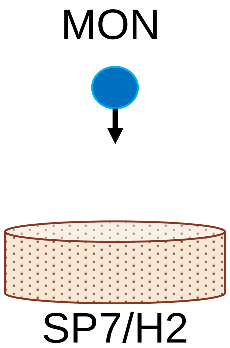
- Penn State and Purdue identified two top candidates with NTO/MON3



H1

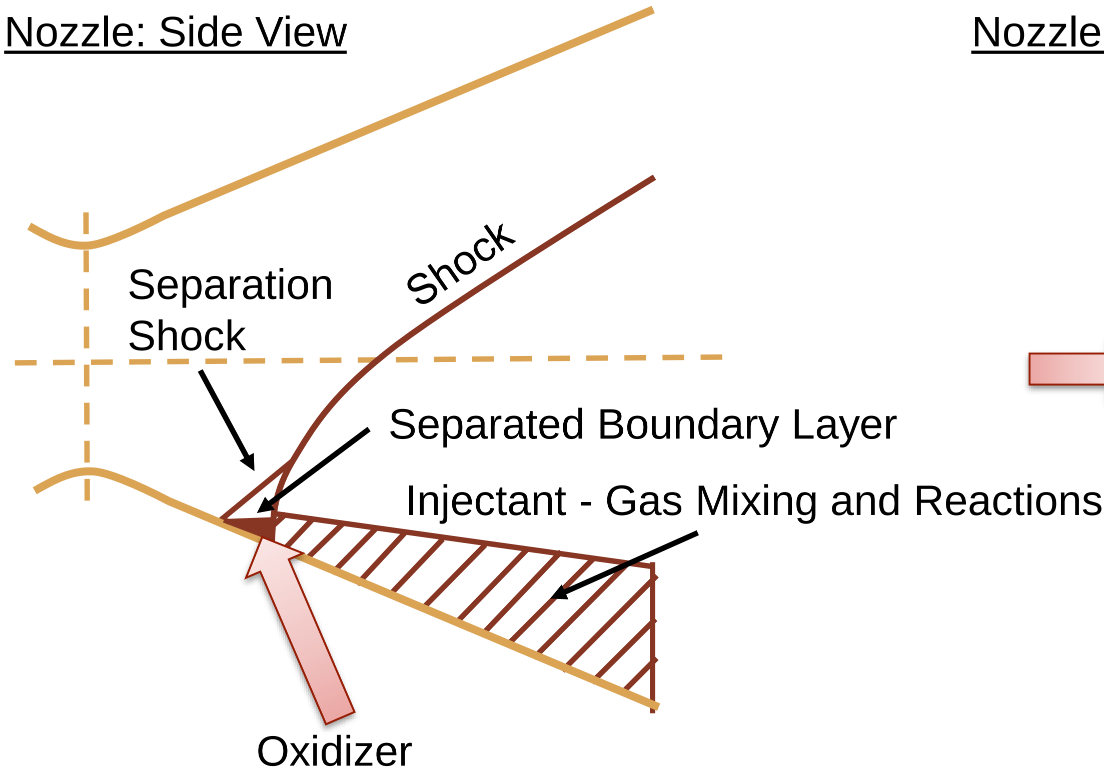
H2

- Purdue then mixed H2 with SP7.
  - Hypergolic behavior exhibited with high loading and exposed reactants on surface (representative of second burn).



LITVC

- LITVC Performance is influenced by location of injection point and discharge angle.



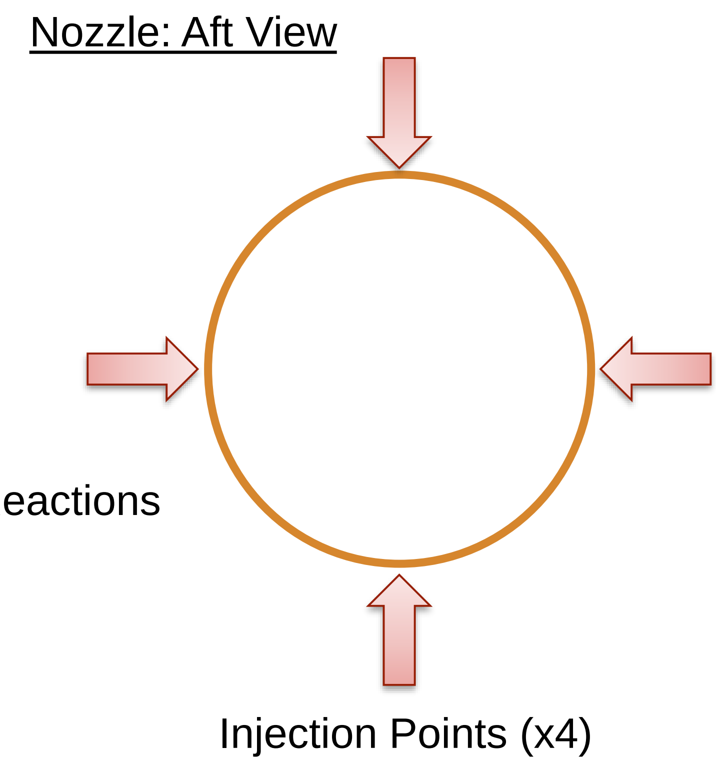


Image adapted from Zeamer, JSC Vol 14 No 6 June 1977 Liquid Injection Thrust Vector Control

Key Challenges

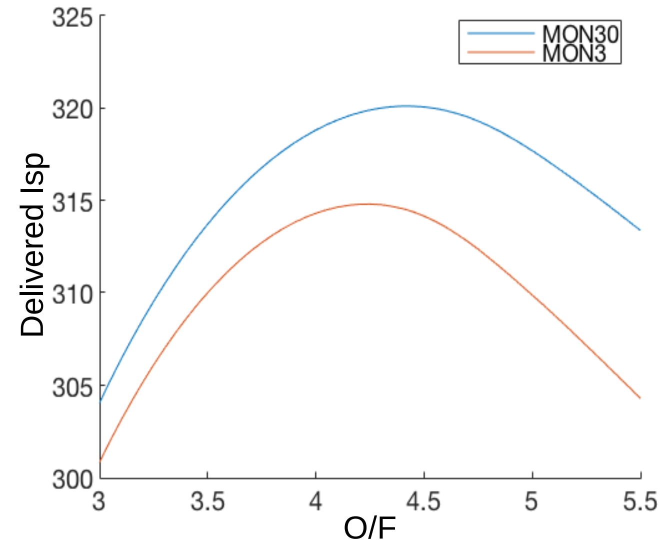
- There are many challenges to developing a new propulsion system for a potential flagship mission.
- Comparatively low TRL of propulsion system
  - A new fuel formulation was developed to survive the Mars environment and first tests were done in FY15
  - Just started MON testing at the end of FY16
    - Only 8 successful tests so far. Many more to be completed in 2017
    - Only about half of the oxidizer mass flux regime has been investigated so far.
    - No regression rate information from full scale tests yet (will be gathered this year).
- Multiple ignitions
  - Hypergolic ignition has been confirmed in a droplet test environment.
  - Testing in Purdue’s 5 cm motor will confirm the behavior in a more realistic, but still ambient, configuration.

Key Challenges

Mars Ascent Vehicle

- Current hotfire testing with MON3 instead of MON30
  - MON3 can be more easily procured and can be used at ambient conditions on Earth.
  - Testing with MON30 during the initial technology development phase is prohibitive from a cost standpoint. MON30 will be considered in 2019.
  - Initial testing with MON3 not only reduces costs, but presents a solution for the MAV if a RTG is used instead of solar panels.

	Changes when moving from MON30 to MON 3
GLOM	0.58%
Thrust	0.44%
Isp	-0.35%
Useable Prop	0.73%
Average O/F	-5.56%
Fuel Core OD	-0.70%
Fuel Core L/D	4.83%
Motor Length	2.66%
Motor Mass	1.35%
Loaded Ox	-0.09%
Loaded Fuel	4.63%
Ox Tank Length	-1.52%
Loaded He	-1.26%

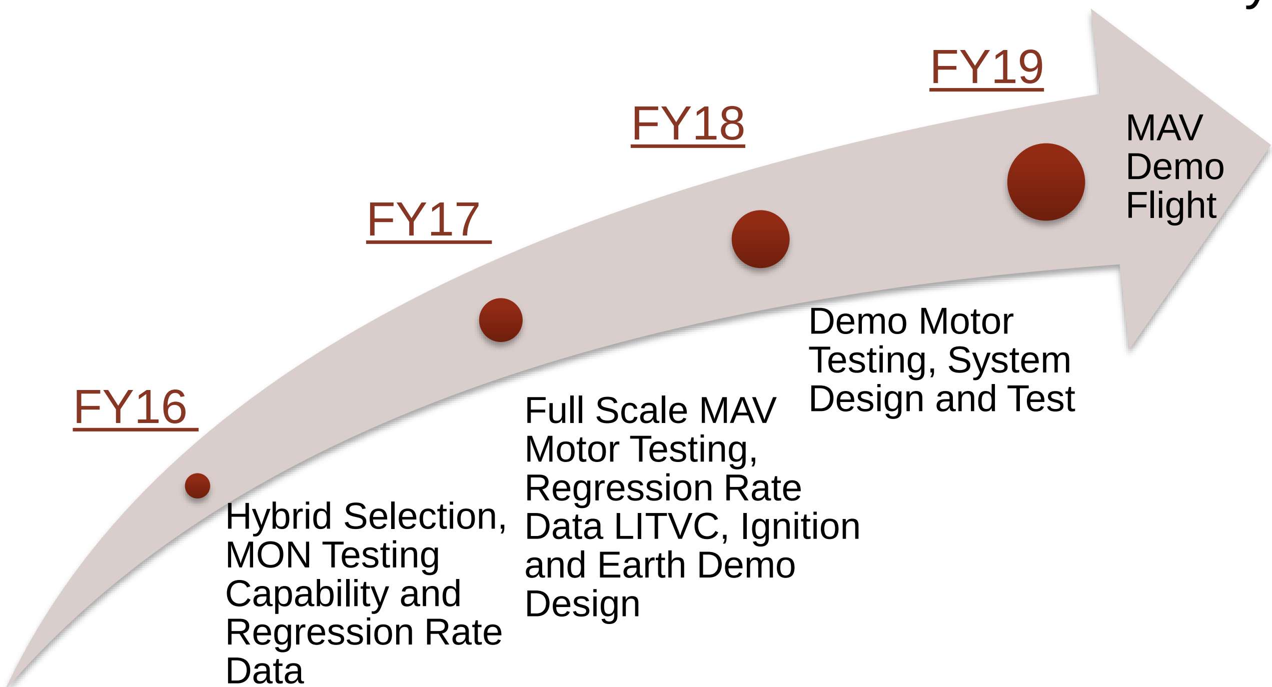


Future Work

- The design presented here is as presented at the Point of Departure Review in December 2016.
  - Modifications to the design for the terrestrial demo are currently underway.
- Completely characterize newly developed fuel (SP7)
  - Hotfire testing with SP7/MON
  - Determine the material properties and processing of SP7 fuel
  - Complete thermal cycling
- Ignition testing
  - Hypergolic ignition method strongly desired
  - Quantify the amount of heat needed to ignite the hybrid.
- Nozzle and TVC testing

Path Forward – Demo Launch

- Technology development to culminate with Earth-based demonstration flight
  - Earth based launch of a hybrid MAV is currently in the planning stages, target mid FY2019
  - Target to match most Mars parameters with Earth based flight
  - Goal is overall risk reduction for future MAV system



Summary

- A wax-based fuel/MON30 hybrid propulsion system is capable of meeting the requirements of a Mars Ascent Vehicle.
- Substantial technology investment is ongoing to develop hybrid propulsion technology for this application (currently TRL 3)
- Full scale testing in FY17 will raise the TRL to 4.
- Major Accomplishments in FY16:
  - First successful tests with SP7/MON3: high regression rate fuel and storable oxidizer. Data are tracking the predictions very well.
  - Multiple solid additives found to be hypergolic with MON.
  - One additive was shown to be hypergolic with MON while mixed into SP7.
  - Preliminary LITVC performance/usage equation has been determined.

- ***While several technological challenges remain, significant development and risk mitigation has already been accomplished in this short time period.***

Questions?

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